Circumstellar Dynamics at High Resolution
ASP Conference Series, Vol. 464
A. C. Carciofi and Th. Rivinius, eds.

On the Binarity of LBV Stars

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Abstract. We report on the binarity of luminous blue variable stars observed with a set of techniques and instruments. Among them, observations at high angular resolution with the VLT-NACO, the VLTI-AMBER and with spectrographs such as the VLT-XSHOOTER allowed us to find several LBV stars as binaries or having a potential companion. In particular the LBV Pistol Star clearly presents radial velocity variations and line profiles modifications (double peak appearance). In addition, the absorption component of the P Cygni lines varies as well with the time indicating a potential wind structure variability. Our observations also show directly for the first time a companion to at least one of the observed LBVs (HD 168625). This one seems to affect the environment of the system. This system is known to be surrounded by several rings similar to those of SN1987A, possibly indicating a future supernova occurrence for this Galactic object. These results show that Eta Car is no longer unique.

1. Introduction

1.1. LBV Stars

Luminous Blue Variable stars are primarily defined by their different time scales of photometric variability, ranging from days to years/centuries with some eruptions. They are also supposed to be an intermediate evolutionary step before the Wolf Rayet phase. According to Groh et al. (2009) the LBV stars know two phases: an eruptive phase, with luminosity exceeding the HD/Eddington limit (Humphreys & Davidson 1994; van Marle et al. 2008). The photometric variability is similar to those of S Dor or η Car. The other phase is the dormant phase in which the LBV does not present any eruptive behaviour, their spectra showing P Cygni lines. They are fast rotators with velocities reaching the critical regime and have as well strong polar winds (Maeder & Desjacques 2001; Owocki 2011). Therefore, their surrounding nebula is often asymmetric, such as the Homunculus nebula around η Car. During their eruptive phase, they can be confused with normal supernovae (SN), they are then called supernova impostors. However, since 5 years, there is more and more evidence than some LBV stars directly exploded as SN without passing through the WR phase (Smith et al. 2007, 2011; Trundle et al. 2008). Such an evolutionary path challenges the current stellar evolution models of high mass stars. See also the contribution by Groh (these proceedings) for more details on the LBV stars in general.

1.2. Binarity in Hot Stars

The main questions about massive stars are how they were formed and how do they evolve?

To form massive stars, it seems difficult to form them in a single star way, especially for the ultra-massive of them, such as often are the LBVs. Therefore, a possibility is to form them in binary or multiple systems. According to Sana et al. (2009, 2011, 2012), 50% to 85% of O stars are binaries, while 30% to 50% of B/Be stars are binaries (Oudmaijer & Parr 2010; Porter & Rivinius 2003). In binary/multiple systems, what is the impact of the companion(s) on the stellar evolution? Is there a mass transfer leading to a spin-up of the gainer, or some interaction, tidal effects between the component that in case of LBV stars could trigger their eruption? What could be the impact of a merger in the activity of the LBV star? There are cases of lower mass stars such as the DPV/LPV stars in which the interaction and mass-exchange is important (see also the contribution by Mennickent in these proceedings). LBV stars are the descendants of the more massive O stars and therefore could be binaries as well. Their direct death in SN (SN IIn) could be explained by their evolution through a binary channel (Smith et al. 2011). However, in LBV stars, up to now, there is only one known binary case: η Car.

1.3. Sample of LBVs, cLBVs

The sample of LBV and candidate LBV stars was chosen among the bright (at least in *K* band with a magnitude lower than 9), relatively nearby stars, and with representative elements from the 3 regions in the HR-diagram defined by the HD limit, and the critical velocity limit for LBV stars (see Fig. 1). And, of course, they were also selected according to their coordinates in the samples of Clark et al. (2005); Nazé et al. (2012). Finally, the sample consists of

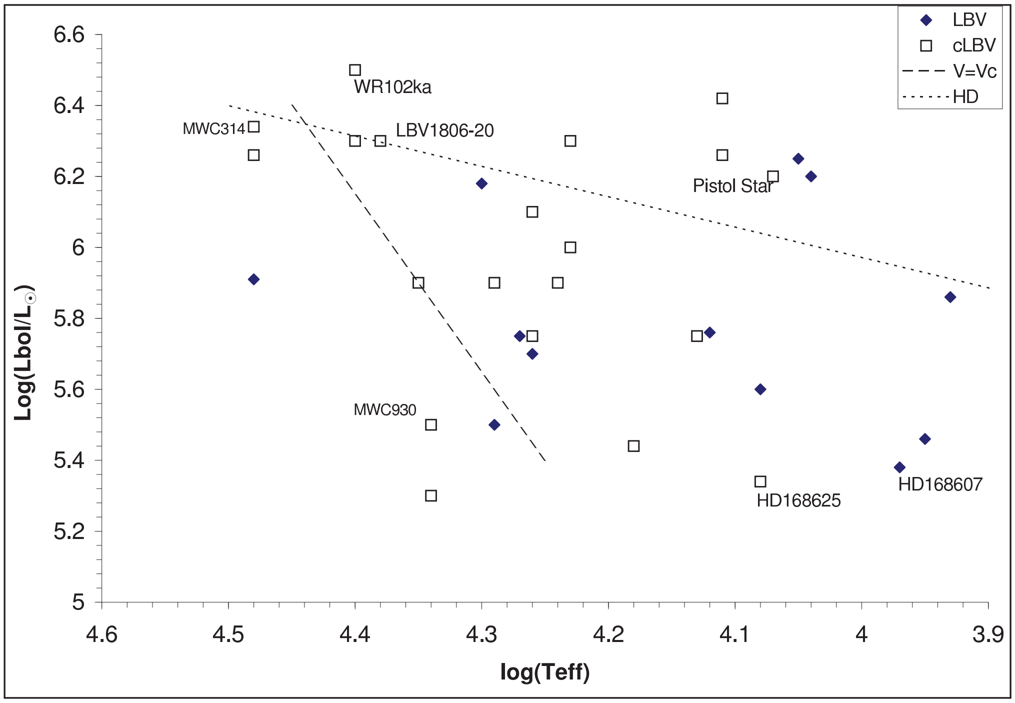

Figure 1. H-R-diagram of LBV and cLBV stars from the samples of Clark et al. (2005); Nazé et al. (2012). The dotted curve shows the HD limit, and the dashed curve shows the limit in which the critical velocity is reached by the LBV stars according to Groh et al. (2009). The stars in our sample are indicated in the diagram.

- Pistol Star: 17h46m15.240s –28°50′03.58″ K=7.3
- HD 168607: 18h21m14.885s –16°22 31′.761″ K=3.5
- HD 168625: 18h21m19.548s –16°22′26.057″ K=4.1
- LBV 1806–20: 18h08m40.31s –20°24′41.1″ K~8
- MWC 314: 19h21m33.975s +14°52′56.889″ K=5.0
- MWC 930: 18h26m25.24s –07°13′17.8″ K=5.3
- WR 102ka: 17h46m18.12s –29°01′36.6″ K=8.8

2. Techniques, Methods, and Instruments

To determine whether a star is binary or not there are several methods of investigations. We mainly used the the chance projection alignment method, used for B/Be stars by Oudmaijer & Parr (2010):

- The stellar density was estimated in 10″ × 10″ field of view close to the region of interest.

- The ranges of magnitudes is also taken into account.
- The chance probability of alignment is computed, taking into account a projection factor corresponding to the most probable angle.

To consider whether the close object is bound to the main star, we used a conservative bound distance of lower than 10 000 AUs in binaries (Longhitano & Binggeli 2010; Lépine & Bongiorno 2007; Sesar et al. 2008; Sana & Evans 2011). We also considered that the flux ratio between the potential companion and the main star must not be larger than 500 (in *K* and *L*' bands), as otherwise the star is probably a back- or foreground star.

Additionally, there is the radial velocity monitoring, mainly with infrared spectroscopy because some of these stars are highly extincted in the optical due to their huge surrounding nebula.

Therefore one has to probe at different scales and at different wavelengths the environment of the LBV stars. We used:

- Imaging, in the far IR with VISIR (Lagage et al. 2004).
- Near/mid IR adaptive optics imaging with NACO (Lenzen et al. 2003; Rousset et al. 2003).
- Interferometry with NACO SAM (Tuthill et al. 2006) and VLTI-AMBER (Petrov et al. 2007).
- Spectroscopy with X-shooter (Vernet et al. 2011), adaptive optics IFU SINFONI (Eisenhauer et al. 2003; Bonnet et al. 2004).

The Pistol star is the only star of the sample observed with all these techniques. The other ones were mainly observed with NACO in *K* and *L*' bands.

Note that MWC314 is also followed up with HERMES spectroscopy by Lobel et al. (in preparation). In the following, we report the results mostly coming from our NACO observations.

The results of the chance alignment method is presented in Table 1.

3. Special LBVs

3.1. Pistol Star

The Pistol star is known for its huge surrounding nebula, ejected in a previous eruption several thousands of years ago. The stellar mass is about 150 – 200 $M_\odot$ (Figer et al. 1998, 1999). The Pistol Star was found to be a binary, with a companion at 10 – 50 mas separation with the VLTI-AMBER by Martayan et al. (2011). Our NACO images show a lot of nearby objects but none of them should be bound to the main star.

3.2. HD 168625

This star is known for its nebular rings (O'Hara et al. 2003). With NACO we found a companion at 1.15″. Its *K*, *L*', *M*' fluxes seem to indicate a red cool object. Because it is "widely" separated from the main star, there is an unique opportunity to get a direct diagnostics on its nature and therefore strongly constrain the LBV formation and evolution.

Table 1. Change alignment probability of visible companions in NACO adaptive optics images. For each star the limit in ″of stars bound gravitationally is given in col. 1. In col. 2 the projected distance to the main star is given in ″. In col. 3 the chance of alignment is given in % taken into account a projection factor with the most probable angle. In the same column is given the status of the object: bkg for background star, a ? indicates the uncertainty on this status, "potential" means the detection has to be confirmed. The final status bound or background is given taking into account the criteria detailed in Sect. 2.

Star (limit bound stars)	NACO Nearby objects	Status (Probability %)
Pistol Star	0.75″	53%, bkg
(0.98″)	1.02″	Too far, bkg
HD 168625	1.15″	<3%, bound
(3.7″)	4.75″	Too far, bkg
MWC 314	0.3″?	Potential, 1.4%, bound?
(2.7″)	1.2″	22%, bound
	1.7″, 2.1″	44% and 67% but faint, bkg
MWC 930	0.8″?	Potential, 5%, bound?
(2.0″)	1.35″	14%, faint, bkg
LBV 1806–20	0.8″	Faint + too far, bkg
(0.7″)	0.95″	Too far, bkg
WR 102ka	1″	50%, bound?
(1.0″)	1.3″	Too far, bkg
HD 168607	1.4″?	Potential, 12%, faint, bkg?
(2.9″)	2.2″?	Potential, 19%, faint, bkg?

3.3. Other LBVs

The LBV 1806–20 was observed by Figer et al. (2004), they report with a single Keck-NIRSPEC McLean et al. (1998) observation the presence of a double line He 1700 nm. This one could possibly be related to binarity, but this must be monitored for a potential profile and RV evolution with time.

The LBV MWC 314 is monitored with HERMES (Raskin et al. 2011) and was found to be binary with a period of about 61 days and an eccentricity of the orbit of 0.3, based on the Si II 545.5 nm line profile and RV evolution, as reported by Lobel et al. (2011). In addition to the companion found with our NACO observations, this star appears to be a multiple system.

4. Binarity Status

The final result about the binarity status of the LBV of our sample is given in Table 2.

5. Conclusions

- η Car is not anymore alone as LBV-binary.
- Pistol Star, HD 168625, MWC 314 are binaries as well.

Table 2. Binarity status, η Car is indicated for reference purpose

Star	Binarity status	Period
η Car	Close (30 AUs)	5.5 years
Pistol Star	Close (80–400 AUs)	90 d to 725 d
HD 168625	Wide (>2500 AUs)	$N\times1000$ years?
MWC 314	Close+wide (3 AUs, >3600 AUs)	60 d and $N\times1000$ years?
MWC 930	Candidate wide	?
LBV 1806–20	Candidate close	years?
WR 102ka	Candidate wide	?
HD 168607	N/A	N/A

- At least 11 to 20% of LBVs/cLBVs are binaries.
- Statistically, at least 50% of LBV should be binaries.
- There are different (separation/period) binarity scales among LBVs.
- The question about the influence of the companion(s) remains open.
- According to Kashi & Soker (2010); Kashi (2010) the LBV eruption could be triggered via mass transfer.
- The SN and nebular rings could be triggered via binary mergers, as e.g. SN1987A (Morris & Podsiadlowski 2009), and the SN IIn types of LBV stars can be explained in binary scenario (Smith et al. 2011).

Acknowledgments. Observations were carried out under GTO program ID 085.D-0125(A), normal program IDs 085.D-0625(A,B,C), 087.D-0426(A to G). CMa is grateful to ESO colleagues (astronomers, telescope operators, engineers) for their help in this study. This research has made use of the Simbad and Vizier databases maintained at CDS, Strasbourg, France.

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Discussion

Groh: regarding the companion of the Pistol Star, what should be your best estimate on its nature? eg, flux ratio, mass ratio?

Martayan: From our VLTI-AMBER measurements, the flux ratio is 1 to 2 and from our X-shooter spectra, one can see He lines for both objects. Therefore the companion should be an hot star as well.

Ueta: HD 128625 has an inclined dust torus. Does the presence of the binary companion affect the formation of the circumstellar toroidal structure in any way? Actually, the position of the binary shown during the talk seems to be ∼90°offset from the expected PA of the equatorial plane of the torus.

Martayan: There is a projection effect, if the companion is actually bound to the main LBV star, then the orbital plane is quasi at 90°of the main nebular structure (same as for η Car) but quasi parallel of the dust rings plane. According to the models of Morris & Podsiadlowski (2009), rings structure can be obtained by merger and the mass loss leading to the rings will come from medium latitude of the star. Similar phenomena seem to occur in planetary nebula for which the binarity is often invoked to explain the asymmetries.

(Photo: TRi)

J. Sundqvist (Photo: ACa)